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Repair and Replacement of Acid-Damaged Piles

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ABSTRACT

A case history of the investigation and repair of severe foundation damage by sulfuric acid attack to the concrete piles supporting a chemical plant is described. In December 1975, several columns were observed to have settled up to 5 inches (13 cm). Since large quantities of sulfuric acid are used at the plant, deterioration of concrete piles supporting the structure was suspected. An initial investigation consisting of the coring of numerous floor piles was performed in order to determine the magnitude of the problem. Because many piles were found to be severely deteriorated, underpinning of columns in the area of known damage was begun. During initial underpinning operations, additional investigations (additional coring, laboratory testing, examining piles uncovered by exacavation) were performed. Ultimately, many columns were underpinned at great expense, and significant steps were taken to minimize the possibility of recurrence of the situation. The damage to concrete foundations which can occur in a hostile environment is shown dramatically. The extreme importance to the safety of the structure in minimizing acid spills and leaks into the groundwater or soil is demonstrated.

INTRODUCTION

An industrial process plant located on the Atlantic Coast began to exhibit foundation distress in late 1975. Because large quantities of sulfuric acid are used at the plant, deterioration of its pile foundations was suspected.

A two-phase investigation was undertaken to determine the cause and extent of the damage.

BACKGROUND INFORMATION

The plant described herein is located on the Atlantic coast in the Southeastern United States. It was constructed in the mid 1950's at a site consisting of 30 to 50 ft (9 to 15 m) of very soft marsh clays and silts overlying firm sands. Groundwater is within 4 ft (0.6 m) to the ground surface, and fluctuates a few feet in response to tidal influence. The marsh deposits are so weak and soft that thin-shell cast-in-place concrete piles were utilized to support not only the superstructure but also the floor slab. These piles are 16 in. (40 cm) in diameter at the top.

Large quantities of sulfuric acid are used in the plant. The acid is not confined to pipes, but flows in grated flumes depressed below the floor to sumps, from which it is recirculated. These flumes and sumps were constructed with acid-resistant brick and mortar. Quite frequently, the flumes and sumps overflowed, causing the acid to cover large areas of floor slab.

Numerous open, fluid-filled tanks are located on the plant's second floor, 30 ft (9 m) above ground level. These tanks span 30 ft (9 m) between two column rows. A difference in fluid depth at the two ends of several tanks, indicating differential vertical movements of the two column rows, was observed in December 1975 by plant personnel. This was the first indication of any foundation problems.

Plant personnel began level surveys at that time. By comparing elevations of reference features on columns with design drawings, settlement of approximately 1 to 5 in. (2.5 to 13 cm) was estimated for six columns.

Although comparison of elevations with design drawings is an inexact technique for measuring movement, it was the only method available in this instance, since as-built drawings were unavailable. The results gave reasonable agreement with the magnitude of movement estimated by visual observations.

Plant personnel directed an immediate program of underpinning the 3 most critical columns (those which exhibited the most settlement), by driving new piles around those columns and transferring the loads to the new piles through steel frames above the floor.

INVESTIGATION

In March 1976, an extensive investigation of the situation was begun. The objective of the initial phase of the investigation was to determine the magnitude and approximate lateral extent of the problem.

Because of thick pile caps and pedestals, as well as piping and equipment restraints, investigation of piles supporting columns was not feasible. The shallow groundwater and very soft soils would have greatly complicated excavation of observation pits beside piles, so this approach was rejected. Practical considerations of access to the tops of piles beneath columns and the desire to investigate the full depth of damaged piles made use of ultrasonic evaluation techniques inappropriate. However, the floor slab is supported by the same type of thin-shell cast-in-place piles as the columns, so coring of floor piles was selected as a reasonable approach in determining the magnitude of the situation.

The area of greatest possible damage was known in general terms on the basis of: (1) area of observed column settlement, (2) limited observations by plant personnel of the upper 1 to 2 ft (0.3 to 0.6 m) of floor piles at the locations where the slab had been broken away to allow groundwater sampling, and (3) knowledge of areas of greatest concentrations of sulfuric acid in the plant operations. Ten piles in this area were initially cored with a double-tube, NX-size core barrel, providing cores of 2.1 in. (5.4 cm) diameter. Most of the cores showed evidence of severe deterioration. Attempts to determine the relative variation of pH laterally from ground water samples or with depth from soil samples from two soil borings were unsuccessful because of a neutralization program previously instituted by plant personnel. Such data, if determined, could have been useful in defining the limits (laterally and with depth) of the problem.

As a result of this initial investigation, underpinning of columns in the area of known damage was begun immediately, and further investigation was simultaneously undertaken to better define the extent of the problem. An additional 33 piles were cored. Core locations are shown on Figure 1.

During underpinning, numerous pile caps and the upper few feet of piles were examined from pits excavated by hand to permit underpinning. Information on concrete condition was determined visually and by chipping away concrete with a small rock hammer. Such direct observations were compared with data from cores to enhance data interpretation, and to refine the limits of the damage.

Numerous specimens of cores from the area of greatest damage were selected for laboratory testing and examination. Several specimens were cut and polished for microscopic examination. Chemical tests on finely ground samples of concrete were performed to determine both water-soluble and total sulfate content. Two samples of crystalline growths observed in many of the air voids of all the cores were subject to X-ray diffraction analysis.

RESULTS

Most of the 43 cores showed evidence of se deterioration, as indicated on Figures through 4, which indicate pictorially condition of representative cores. In gene the deterioration was most severe bet depths of 2 to 6 ft (0.6 to 1.8 m), several cores recovering no concrete wi this range. Some damage as high as 12 in. cm) was also noted. At two locations, soil was found below about 2 ft (0.6 m).

The situation was assessed as very criti with respect to safety of the structure. production line in this area was closed underpinning of columns was begun on a thr shift schedule. Replacement piles were jac and driven in very confined locations. Und pinning required excavation of pits genera 6 to 8 ft (1.8 to 2.4 m) deep by hand, provide for pile installation. Numer original piles and pile caps were exami from these pits, and from a few pits excava specifically for exploratory purposes.

The conditions observed from pits genera confirmed the results of the coring progr The first pit was excavated adjacent to one the columns which had originally settl revealing the existence of the problem. pile cap concrete showed evidence of sev deterioration. The matrix exhibited lit strength and behaved essentially as a sa It could be easily chipped away by hand wit hammer. One of the replacement piles at t location had been driven through a corner the cap. No evidence of the piles observed for a distance of several fe beneath the cap.

Subsequent pits revealed a wide range conditions, varying from little or no dam to complete deterioration and absence concrete. Some piles were found to ha suffered relatively minor damage. At the locations, some deterioration of steel she and/or pile was apparent. In general, t shell had disappeared. In some cases, t outer concrete (retaining the corrugat surface imparted by the shell) appeared to hard and intact. In many instances so concrete damage had occurred. By chipping the pile and cap concrete with a sharp hamme the concrete quality was roughly establishe At many locations apparent damage was limit to the outer 1 to 2 in. (2 to 5 cm) of t pile. Other piles were more severely damage and 4 to 6 in. (10 to 15 cm) of concrete cou be easily and quickly chipped away. So could be cut through entirely in a matter minutes. A few of these severely damag piles still contained a central section hard, essentially undamaged concrete, but th core was often no more than 6 in. (15 cm) diameter (10 to 20 percent of the origin cross-sectional area).

On the basis of all cores and pits describ above, the limits of the damaged area we defined with reasonable confidence (see Figu 1). The area of damage had dimensions approximately 60 by 290 ft (18 by 88 m centered longitudinally on an acid flume.

FIGURE 1

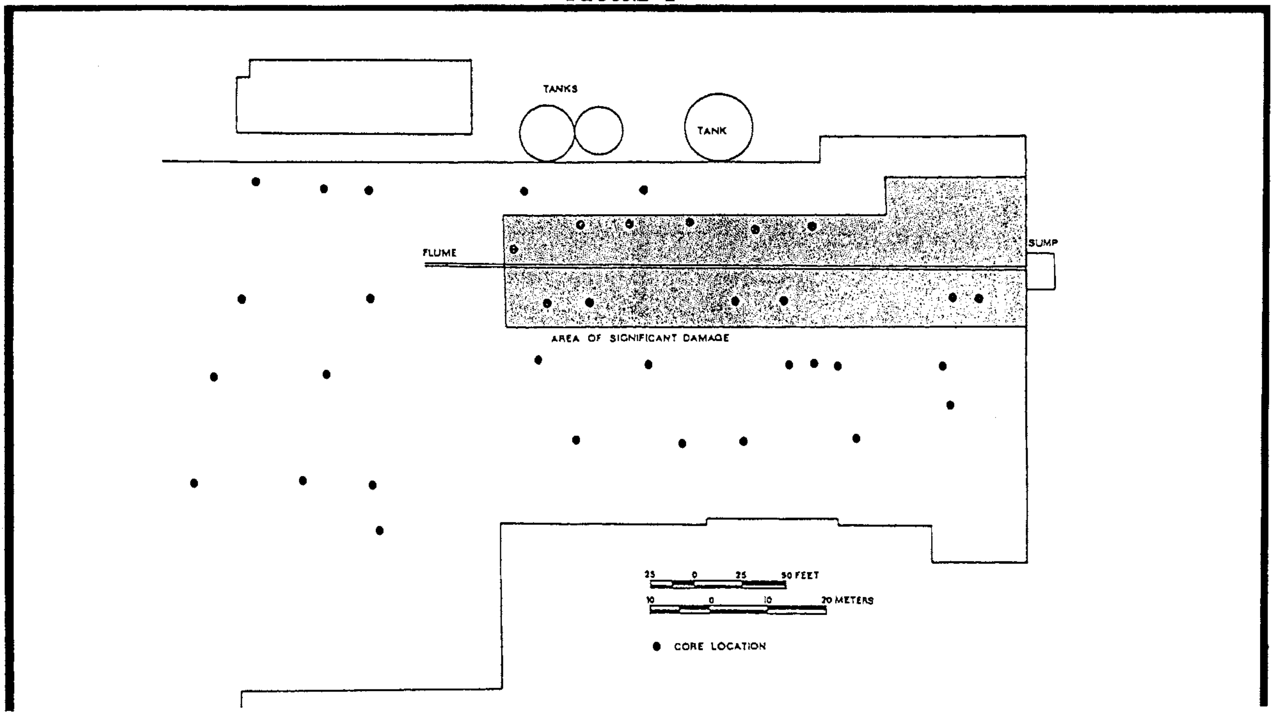


FIGURE 2

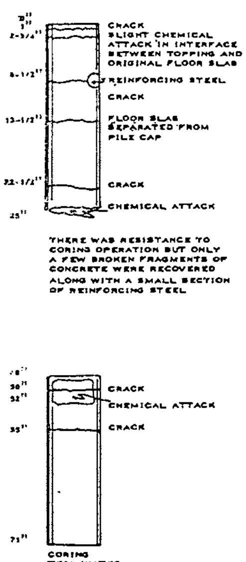


FIGURE 3

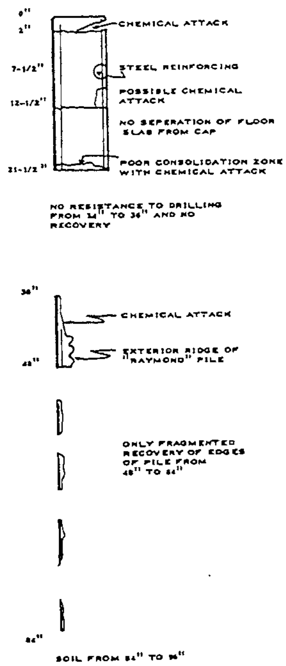
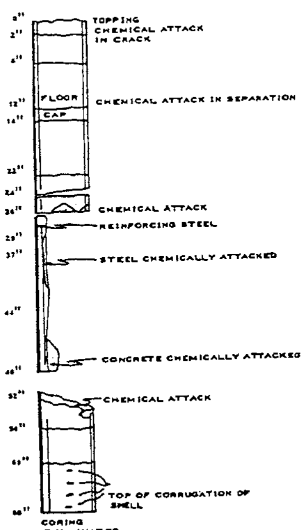


FIGURE 4



Many of the concrete specimens exhibited very high sulfate contents. Approximately half the specimens had total sulfate contents of 15,000 to 115,000 ppm, much in excess of the 2000 - 4500 ppm range anticipated for unaffected concrete. Severe attack by sulfuric acid is thus indicated. Further, high water-soluble sulfate contents correlated very well with concrete samples which showed visible deterioration.

The diffraction analysis indicated that crystalline growths in the air voids were primarily ettringite. Ettringite is a calcium aluminosulfate crystal formed when certain alumina-bearing compounds are present in the cement of a hardened concrete which is exposed to water containing sulfate ions. The formation of ettringite can be accompanied by a volumetric expansion within the cement paste which can disrupt the gel structure and result in deterioration of the concrete.

The existence of ettringite was widespread, but the crystal growths had not yet progressed to the point where they were contributing significantly to the concrete deterioration. Because of potential future problems resulting from crystal growth, periodic microscopic examination of concrete specimens to check for growth is planned.

REMEDIAL MEASURES

Concerns relative to structural integrity and safety were responsible for a decision to close the production line in the critical area and institute an immediate repair program. Many columns were ultimately underpinned by installing four 75-ton (667 kN) piles around each of the affected columns. These open-end steel pipe piles were 12.75 in. (32 cm) in diameter, and were initially jacked to refusal with a 16-ton (142 kN) force (limited by available reaction) and then cleaned out by jetting. The pipe was rejacked to refusal and a tremie seal placed to permit dewatering of the pipe prior to concreting. Three load tests were performed to determine depth criteria for the desired working load. The penetration required was such that jacking was abandoned as too time-consuming, and a small hammer mounted on a forklift was subsequently utilized.

In order to minimize the possibility of acid damage to the new piles, an acid-resistant liner was utilized. After installation of each pipe and dewatering, a heavy polypropylene liner was dropped down the pipe for a depth of 20 ft (6 m). Then the pile was concreted. The function of the liner is to protect the concrete from further acid attack. The concrete section was designated to carry the design load, even if the steel pipe is lost to acid attack. The liner could not extend to the pile tip, since this would eliminate the available skin friction in the lower few feet. Much deeper, and impractical, penetration would have been necessary to develop the required capacity in end-bearing alone. The liners were placed from floor level to well below the zone of damage.

Consideration was given to the possibility acid leakage downward along the outside of steel shell to a level below the liner, this was dismissed as a significant conc because the soft clays along the pile v squeeze considerably, effectively closing interface between pile and soil.

Some large tanks at ground level v supported by piles beneath individual t legs. These large tanks had bottoms abou ft (0.3 m) above the floor slab. Because this extremely low headroom, underpinning replacement piles was not feasible. Inste the tanks were emptied to reduce the load the pile beneath a single leg was exposed hand-excavated pits. The damaged length this pile was removed by hand, so that o the lower, undamaged section, remair Generally the upper 8 to 10 ft (2.4 to 3 was removed. Dowels were drilled and grou into the upper end of the remaining p section, and a new upper section was for and cast. After one tank leg pile repaired in this manner, another was do until the tank supports were complet replaced.

As described earlier, minor damage to s piles was discovered on the preriphery of badly damaged area. In instances where onl thin outer zone of the piles was damag their ability to safely support the impo loads was judged to be essentially unimpair No remedial measures were taken, but th areas will be periodically reinspected as safety measure.

An integral part of the repair program was effort to repair flumes, sumps, floor sla etc. to prevent future acid leakage. Flu and sumps were removed and reconstructed us acid-resistant materials. Cracks in sl were sealed. Piping, pumps, etc. were repai as required.

CONCLUSIONS

Deterioration was the result of acid atta It varied in severity from a condition of l of steel pile shell but little or no concr damage, to a condition of loss of ent piles. Intermediate conditions of damage the outer several inches of pile were a found. After the acid attack, primar insoluble residue or insoluble products of reaction remained, in place of the concrete

This situation dramatically demonstrates damage which can occur to concrete fundati in a hostile environment. The safety of large structure was seriously impair requiring an extensive repair program. extreme importance of minimizing acid spi and leaks into the groundwater or soil shown, relative to the safety of the struct as well as the usual environmental concerns